

# STUDIES ON THE EARTHWORMS OF TURF

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## B. EARTHWORMS AND SOIL

### I. INTRODUCTION

Despite the wide range of soil conditions encountered in the untreated and fertilizer treated plots of Set D, on the Experiment Ground at St. Ives Research Station, Bingley, the framework of the earthworm populations of most of these plots consisted of *Allolobophora terrestris* Sav., members of the *A. caliginosa* complex and *Lumbricus* spp. (*terrestris*, *rubellus*, *festivus*, *castaneus*). However, the size of populations varied from 0— $\frac{1}{2}$  million per acre (Jefferson, 1955) and there were within these populations some individual responses to the environment.

Since earthworms are scarce in acid soils the present investigation is concerned mainly with the influence of acidity and exchangeable calcium on populations.

### 2. MATERIAL AND METHOD

Details of the experimental area at St. Ives, and methods of sampling earthworms are given in this *Journal*, No. 31 (1955).

#### (a) *Soil sampling*

A borer ( $\frac{5}{8}$  in. diam.) was employed to collect samples to a depth of  $4\frac{1}{2}$  in. in a random manner.

#### (b) *Soil analysis*

To facilitate direct comparison results are expressed (where applicable) on a moisture free basis. The following methods were used:

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\* Mr. P. Jefferson started his studies of earthworms while on the staff of the St. Ives Research Station, Bingley, and has continued them from the Nottingham and District Technical College.—Ed.

*Soil pH* was determined at 18°—20°C on a soil:water suspension (1:2½) (after one hour's mechanical shaking) by means of a pH meter with a glass electrode.

*Exchangeable bases*.—These were extracted by leaching with ammonium chloride solution, results being expressed as milligram-equivalents per 100 grams of dry soil (m/e per 100 g.).

*Carbonate*.—Total carbonate was measured with a Collin's calcimeter, results being expressed as calcium carbonate (CaCO<sub>3</sub>).

### 3. OBSERVATIONS

#### (A) SOIL ACIDITY

##### (a) Soil reaction and total populations

It has long been known that earthworms are scarce in very acid soils but the exact relation of the Lumbricidae to soil acidity has not been explained satisfactorily. Some species are more tolerant of acidity than others, see Table 1.

TABLE 1

*The lowest and highest soil pH at which earthworms were recorded*

Species	Lowest pH	Highest pH
<i>Allolobophora terrestris</i> f. <i>longa</i> Ude	5.1	8.0
<i>A. caliginosa</i> Sav. ... ..	4.0	8.0
<i>A. chlorotica</i> Sav. ... ..	5.0	6.4
<i>Lumbricus terrestris</i> Linn. ... ..	5.1	7.9
<i>L. festivus</i> Sav. ... ..	5.1	8.0
<i>L. rubellus</i> Hoff. ... ..	4.0	8.0
<i>L. castaneus</i> Sav. ... ..	4.6	7.8
<i>Eisenia rosea</i> Sav. ... ..	5.2	8.0
<i>Octolasion cyaneum</i> Sav. ... ..	5.1	7.8

Text fig. 1 shows the soil reaction of plots (both untreated and fertilizer treated) plotted against the 1947 population estimates. From the scattered points it is possible to discern the following general trends:—

- (i) the smallest populations tend to occur at the extremes of pH.

- (ii) population size tends to increase from about pH 5.0 to a maximum around pH 6.0—6.5.
- (iii) very high densities are not a feature of alkaline soils containing calcium carbonate (though activity as judged by cast formation may be high).
- (iv) in most instances the trend in untreated plots is similar to fertilizer treated areas.

In order to investigate the numerical association between pH and earthworm populations simple regressions were calculated on these population estimates from soils (a) free of calcium carbonate ( $\text{CaCO}_3$ ) (pH < 6.8)\* and (b) containing  $\text{CaCO}_3$  (pH > 6.8).\* A positive correlation was obtained from acid plots but this was only just significant at the 5% level ( $r = +0.397$ ) even with the "weighting" from plots without earthworms. The correlation for alkaline plots was negative but not significant ( $r = -0.057$ ).

(b) *Exchangeable calcium*

(i) *Exchangeable calcium and total populations*

Calcium was the most abundant exchangeable metal ion in untreated and fertilizer treated plots (Table 2) and in most instances the soil pH was closely related to the amount of exchangeable calcium.

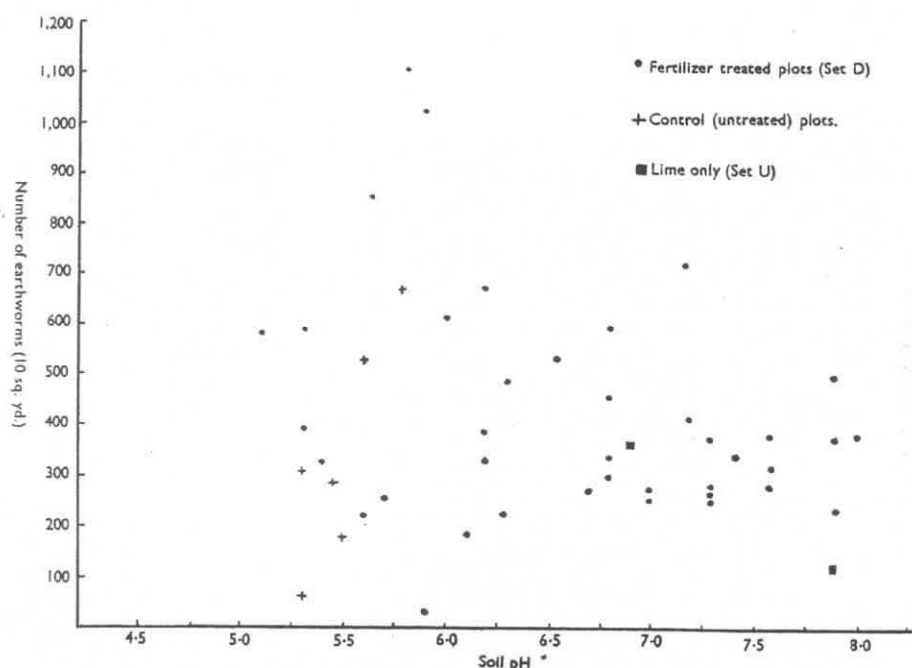
TABLE 2

*Exchangeable metal ions in the soil of some experimental turf plots (m/e per 100 g. of soil)*

Plot No.	Sodium nitrate	Sodium nitrate	Control	Nitro chalk
	III.3	VII.3	VII.1	III.10
pH ... ..	6.2	6.3	5.5	6.6
Exchangeable Calcium ...	7.7	7.3	4.4	10.5
„ Potassium ...	0.8	0.4	1.0	0.8
„ Sodium ...	2.6	2.8	†—	1.5

\* The sign > means greater than and the sign < means less than. These are used for brevity throughout.

† Not estimated.

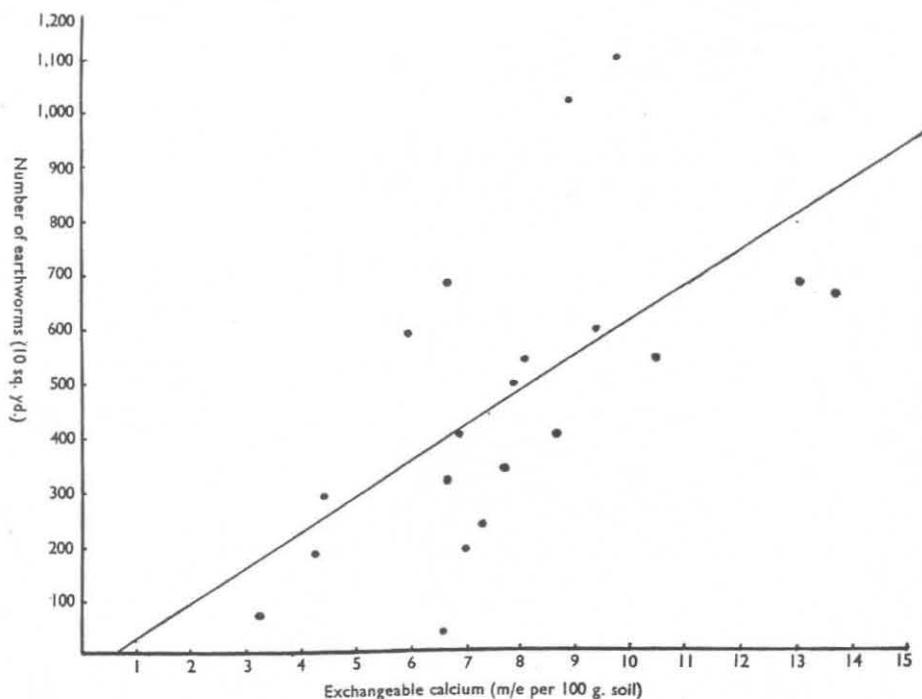


TEXT FIG. 1—Earthworm populations and soil pH, October 1947 (Earthworms absent below pH 5.0).

Since weak positive correlations were obtained as between earthworm populations and soil reaction in plots pH < 6.8 simple regressions were also calculated on earthworm counts (1947) and exchangeable calcium. These acid soils devoid of calcium carbonate gave (text fig. 2) a positive correlation between exchangeable calcium and populations, significant at the 1% level ( $r = +.602$ ) (20 items). Samples from 11 acid plots (October 1954) were also positive and significant at the 1% level ( $r = +.831$ ).

Further studies on acid areas suggested that exchangeable calcium was equally important on untreated and fertilizer treated plots since a parallel trend was apparent up to 10-12 m/e per 100 g. In sodium nitrate plots where the relation of population to pH was obscure, the population (1947) increased from 182 to 487 in the exchangeable calcium range 6.6—8.7 m/e. In 1954 a similar trend was apparent (text fig. 3). On control areas where the relation between pH and exchangeable calcium was less obscure, there being no interference from metal ions applied with fertilizers, exchangeable calcium again appeared to be an important limiting factor in the range 3—8 m/e (text fig. 3). The largest earthworm populations were found in the calcium range 8-14 m/e per 100 g. soil corresponding (in the absence of

excess sodium ions) to pH 5.8—6.8 and below this value the influence of calcium was extremely critical.

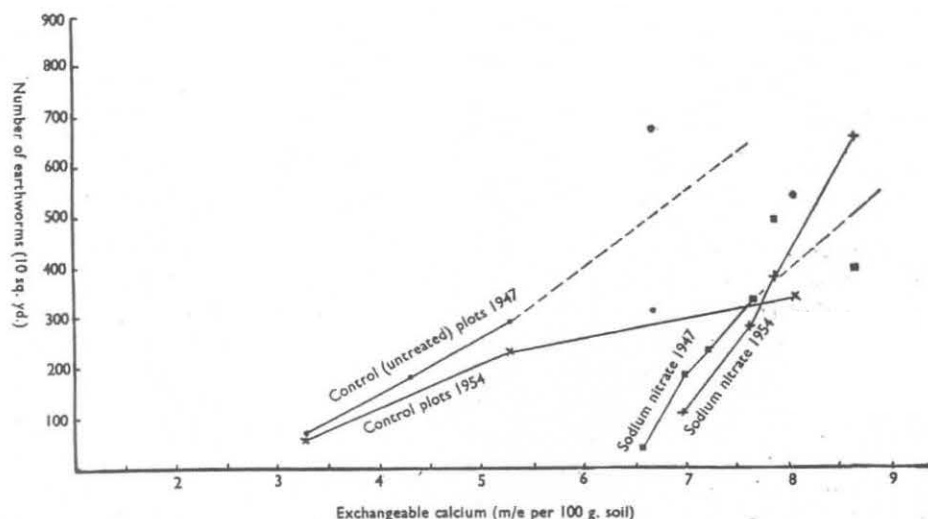


TEXT FIG. 2—Earthworms and exchangeable calcium, October 1947

Where an alkaline soil was induced by liming (or dressings of sea sand) the exchangeable calcium content of the soil generally exceeded 18 m/e per 100 g. Here calcium carbonate was present in varying amounts and a high percentage of the total base exchange capacity was satisfied with calcium ions. As conventional techniques failed to distinguish adequately the exchangeable calcium from the calcium present as calcium carbonate correlation tests were not carried out with exchangeable calcium and populations in alkaline soils.

(ii) *Exchangeable calcium and species*

The species in the populations (*A. terrestris* Sav., *A. caliginosa* Sav., *Lumbricus* spp.) showed, in general, a similar response to exchangeable calcium within the range 3—10 m/e per 100 g. (pH 5.0—6.0) a critical relation being apparent in both untreated and fertilizer treated areas. The maximum density seemed to occur between 8—14 m/e per 100 g., but owing to the fewness of plots at the 9—13 m/e per 100 g. exchangeable Ca.



TEXT FIG. 3—Earthworm populations and exchangeable calcium in control (untreated) and sodium nitrate treated plots.

level the precise optimum was hard to determine. A high density of any one species was not a feature of alkaline soils however (see *Journal* 31, 1955).

#### (B) OTHER FACTORS

During the survey plots were encountered with exceptionally high or low populations for a particular concentration of soil exchangeable calcium (Table 3). Such deviations from "expected" populations might arise as the direct result of fertilizer treatment or from localised differences in the quality of the soil. Moisture characteristics, organic matter, nitrogen and detrimental substances of the soil are all likely contributory factors.

TABLE 3

*Examples of the wide variation of populations at the level 6—7 m/e exchangeable calcium per 100 g.*

Plot	Treatment	October 1947 population estimate	Ex. Ca. m/e per 100 g.	pH
II.20	Urea ... ..	582	6.0	5.1
IV.20	Sodium nitrate + Ferrous sulphate ...	37	6.6	5.9
II.24	Dried blood ... ..	394	6.9	5.3
III.1	Control ... ..	307	6.7	5.3

#### 4. DISCUSSION

Observations on the earthworms of certain turf plots at Bingley have shown that the size of populations varies widely in untreated and fertilizer treated plots on the same soil type. These environments which have received specific treatment for 26 consecutive years, provided a suitable site for a preliminary study of earthworms and soil.

Salisbury (1924), Bornebusch (1936), Russell (1950) and others have drawn attention to the scarcity of earthworms in acid soils. Since the pH of the soil of the above plots ranged from 3.9—8.0 the study of soil reaction and earthworms provided a useful point to start the investigation of a complex of environmental factors.

The scarcity of earthworms in acid habitats has been directly attributed to low pH or a deficiency of exchangeable calcium in the soil. Satchell (1953) concluded that in fertilizer treated plots below pH 4.5 (Rothamsted Park Grass) the variation in density between treatments was directly related to the hydrogen ion concentration. He considered that exchangeable calcium was significant only through its high correlation with soil acidity. In plots with a pH higher than 4.5 however he was unable to account fully for population differences solely on the basis of soil reaction.

At Bingley earthworms were absent (or present in much reduced numbers) below pH 5.0 but above pH 5.0 a marked increase in population size was apparent and the highest densities were found in soil between pH 5.8—6.2. Regression tests showed a greater degree of correlation between earthworms and exchangeable calcium than between earthworms and pH in soils pH <6.8.

In soils containing calcium carbonate (pH >6.8) populations were smaller than at pH 6.0 but a negative correlation was not established in alkaline soils.

*A. terrestris* Sav., *A. caliginosa* Sav. and *Lumbricus* spp. showed a similar response to exchangeable calcium in most untreated and fertilizer treated plots. *Allolobophora terrestris* appeared to be very tolerant of alkaline conditions but died out below 3 m/e per 100 g. exchangeable calcium whereas *A. caliginosa* and *Lumbricus rubellus* were recorded from soils with 0.7 m/e per 100 g. exchangeable calcium (approx. pH 4.0) (see *Journal* 31, Paper A).

Satchell (1953) was unable to find evidence to support the view that a deficiency of exchangeable calcium was a primary reason for small populations in acid soils. This contrary statement was based on the study of

"manured" pasture plots at Rothamsted (1951-52) but of the exchangeable calcium analyses quoted from his 21 plots, 7 soils contained  $<5.25$  m/e and fourteen  $>9.25$  m/e Ca. per 100 g. soil. Further, more than half of these plots received lime or dung every four years. In view of the "gap" in the exchangeable calcium level of these soils (where at Bingley the influence of calcium is most critical) and the large number of lime plots included in the statistical analyses the regressions were probably heavily "weighted" against a strong positive correlation for exchangeable calcium. The population data were collected at intervals over a period of a month.

In the soil of Britain calcium is usually the dominant exchangeable metal ion and in soils with a similar composition there is a relation between pH and exchangeable calcium. Owing to the variation in the proportion of soil minerals and organic matter it is not possible to formulate a general expression for this relationship. Dissimilar soils may have the same pH but contain different amounts of exchangeable calcium since this is dependent on the proportion and nature of the colloidal complex of the soil. For example, at a given pH, peat soils yield higher exchangeable calcium values than sandy loams. Preliminary field observations on a peat soil (pH 4.2) suggest that the density of earthworms is considerably greater than on light loam of similar pH. It would therefore be of considerable interest to study earthworms and exchangeable calcium in other types of soil, especially peat where the critical exchangeable calcium range is probably associated with a lower soil pH than at Bingley.

The development of soil acidity through the gradual displacement of exchangeable metal ions with H ions is progressive in humid climates. The two most important factors involved under natural conditions are (1) the extent of leaching by rainwater charged with carbon dioxide and (2) the formation of acids by the metabolism of living organisms but the rate of displacement is considerably higher in industrial areas where rainwater also becomes charged with sulphur dioxide.

Fertilizers also influence the reaction of the soil. According to their effect on soil reaction, four types of fertilizer treatments were recognised at Bingley, i.e., treatments which (1) accelerated the development of soil acidity, (2) decreased acidity or induced alkalinity, (3) more or less stabilised soil reaction and (4) affected soil acidity to a negligible degree so that the plots closely followed the trend to acidity in untreated areas.

The first group of treatments includes ammonium fertilizers where the loss of metal cations is approximately equivalent to the amount of fertilizer

applied. In the absence of calcium carbonate in the soil the base loss falls mainly on the exchangeable calcium.

The second group of treatments received lime (as carbonate), or other materials containing calcium carbonate in sufficient quantity to increase the total calcium content of the soil.

The third group of fertilizers (calcium nitrate, sodium nitrate) supply sufficient metal cations to more or less offset the annual loss of bases (Table 4).

TABLE 4

*pH and exchangeable calcium in Set D plots*

Treatment	No treatment (control)		Ammonium sulphate			Ammonium sulphate + Pot. sulphate + supers		Calcium nitrate	Sodium nitrate
			alone	+ lime	+ lime + FeSO <sub>4</sub>	alone	+ lime		
pH ... ..	5.3	5.5	4.0	6.8	7.0	4.0	6.8	5.9	6.3
Exchangeable calcium m/e per 100 g. ...	6.7	4.3	0.7	> 18	> 18	< 1.0	> 18	8.9	7.9

Finally most organic fertilizers do not appear to influence greatly the trend to acidity (Table 5).

TABLE 5

*pH of some Set O plots*

	Ammonium sulphate	Control (no fertilizer treatment)	Dried blood	Hoof and horn meal	Rape meal
Soil pH	5.2	5.8	5.8	5.8	5.7

Since repeated treatment with certain fertilizers tended to "iron out" chemical and physical differences in the soil it might be expected that the size of populations in replicate plots receiving a specific fertilizer treatment would also show greater uniformity. It was possible to carry out analysis

of variance tests on populations from five treatments with replicate plots in Blocks II, III, IV, VII, VIII and IX of Set D (Table 6).

TABLE 6

*The populations of 5 replicated treatments—Set D (1947)*

Treatment	Block					
	II	III	IV	VII	VIII	IX
Ammonium sulphate ... }	590	247	333	498	347	216
Ferrous sulphate ... }						
Lime ... }						
Sodium nitrate ...	487	333	182	229	446	394
Untreated ...	179	307	65	287	532	672
Sodium nitrate ... }	403	275	373	377	277	304
Supers, lime ... }						
Ammonium sulphate ... }						
Potassium sulphate ... }	450	294	269	338	269	262
Supers, lime ... }						
Ammonium sulphate ... }						

These tests showed a considerable "between Block" variance ( $Q=19,919.56$ ) but "between treatments"  $Q=2,506.15$ . These population differences suggested that marked soil differences existed from Block to Block but soil conditions and therefore earthworm density were more uniform where fertilizer treatment was carried out (Table 7a).

TABLE 7a

*Analysis of variance tests—Set D population estimates (1947)*

	Degree of freedom	Sum of squares	Quotient
Between blocks ...	5	99,597.8	19,919.56
Between treatments ...	4	10,024.6	2,506.15
Error ...	20	37,351.26	18,675.63
	29	483,135	

The population "within the treatments" showed the greatest uniformity in "complete fertilizer + lime" areas but in untreated plots considerable variation in populations existed (Table 7b).

TABLE 7b

*Variance within replicate fertilizer treated and untreated areas*

Plot treatment	S <sup>2</sup>
Untreated ... ..	42,285.4
Complete fertilizer (ammonium sulphate)+lime	3,898.11
Complete fertilizer (sodium nitrate)+lime ...	6,316.08
Sodium nitrate ... ..	14,163.2
Ammonium sulphate, ferrous sulphate+lime ...	15,970.32

In the case of these plots the high values for the "between plots" variance of populations in untreated plots compared with fertilizer treated plots can be explained by reference to the exchangeable calcium content of the soil. In the former calcium values lie within the critical range (3.3—8.2 m/e per 100 g. soil). In the fertilizer plots, with the exception of sodium nitrate plots, the calcium content of the soil was outside the most critical level of exchangeable calcium and the "between plot" variance of populations was therefore very much lower (Table 8).

TABLE 8

*Population variance pH and exchangeable calcium in replicate plots (1947)*

	Untreated controls	Sodium nitrate	Supers, Potassium sulphate, Lime		Ferrous sulphate, Amm. sulphate, Lime
			+ Amm. sulphate	+ Sod. nitrate	
S <sup>2</sup> ... ..	42,285	14,163	3,898	6,316	15,970
pH range ... ..	5.3—5.8	6.1—6.3	6.8—7.0	7.2—7.4	6.8—7.0
Exchangeable calcium m/e per 100 g. ... ..	3.3—8.2	7.0—8.7	>18	>18	>18
CaCO <sub>3</sub> ... ..	absent	absent	<1%	<1.5%	<1%

Robertson (1936) states that calcium carbonate excreted by calciferous glands of earthworms is chemically inactive and plays no part in modifying the pH of the gut; since earthworms do not appear to have a mechanism for adjusting calcium uptake from the soil, the excretion of  $\text{CaCO}_3$  is a means of eliminating excess calcium not required for metabolism.

Russell (1951) implies however that calcium plays a part in the metabolic processes of earthworms since he writes "most earthworms need a continuous supply of calcium, which they convert into calcium carbonate . . . Earthworms are therefore absent from very acid soils or soil devoid of calcium".

Satchell (1953) expresses the view that a direct relation between soil exchangeable calcium and earthworms is unlikely to exist since in his opinion calcium does not appear to be important in their metabolism. He considers the relation of exchangeable calcium and earthworms is through the correlation with pH, and low pH (<4.5) is responsible for a scarcity of earthworms owing to the repellent properties of the soil.

A close relation appears to exist between exchangeable calcium and earthworms especially in acid soil but there is very little evidence to support the view that the metabolism of earthworms requires a large amount of calcium. Indeed it seems more likely that the function of calciferous glands is associated with the excretion, rather than the conservation of calcium taken from the soil. The question is therefore "why are earthworms scarce in soils deficient in calcium?"

Only a tentative answer to this question can be given and first it is necessary to consider briefly the complex relation of earthworms and organic matter, a subject on which very little experimental information exists. The size of the soil fauna and flora is determined of course by the amount of organic matter synthesised by green plants and returned to the soil. Factors which adversely affect the availability of plant nutrients and the rate of growth, for instance soil acidity, indirectly affect the distribution and size of various soil populations. Furthermore, the metabolism of some soil organisms, notably bacteria, is influenced by acidity or other factors. The inhibition of bacteria has a far reaching consequence; with a slow turn over of organic matter, plant debris accumulates as a surface "mat" and a change from "mull" to "mor" is initiated.

It is very difficult to separate direct from indirect effects on soil organisms but field observations of differences in earthworm activity on closely mown turf where clippings are removed or allowed to stay, suggest that the nutri-

tion of earthworms is dependent on the supply of decaying organic matter. Micro-organisms doubtless play a part in forming a suitable type of food for earthworms. Some supporting evidence is provided by the laboratory work of Evans (1948). In cultures he records a high rate of cocoon production in partially decayed organic matter and low production in originally undecayed or well decayed material.

The size of earthworm populations might be expected to parallel the growth curve for green plants and many soil bacteria. Observations on the experimental plots lend support to this view, for instance, the highest earthworm counts are found in slightly acid and neutral soils where optimum conditions probably exist for decay and growth of vegetation. With increasing acidity the number of earthworms diminishes and they are generally absent in "mor" soil. Decidedly alkaline soils ( $\text{pH} > 7.6$ ) generally carry smaller populations than at  $\text{pH} 6.0$ . Highly acid and alkaline conditions are known to "fix" certain plant nutrients and make their uptake more difficult so that a reduction in the size of populations is not entirely unexpected. Since in most soils,  $\text{pH}$  is closely related to the concentration of exchangeable calcium, a positive correlation between earthworms and exchangeable calcium is also understandable. However, the influence of this cation is probably indirect and connected with the role of exchangeable calcium in the metabolism of green plants and micro-organisms.

## 5. SUMMARY

1. Soil acidity, whether naturally developed or accelerated by fertilizer treatment, is an important factor responsible for marked variations in the size of populations between habitats. A simple regression test (1947) with  $\text{pH}$  ( $< 6.8$ ) and populations was significant at the 5% level ( $r = +.397$ ). The importance of exchangeable calcium (up to 13.5 m/e per 100 g. soil) is also clear being significant at the 1% level ( $r = +.602$  and  $.831$  respectively). Exchangeable calcium is very critical in the range 0.7—8.0 m/e per 100 g. of soil; the optimum is probably about 9—11 m/e per 100 g. soil (corresponding to approximately  $\text{pH} 6.0$  in soil where calcium is the principal exchangeable metal ion). Although the populations of alkaline soils ( $> 18$  m/e per 100 g. calcium) are smaller than those at  $\text{pH} 6.0$  and appear to decrease with increasing alkalinity, a significant negative correlation has not been established.

2. The dominant species (*A. caliginosa* Sav., *A. terrestris* Sav., *Lumbricus* spp.) show a similar response to exchangeable calcium but *A. terrestris* f. *longa* Ude is absent from soils containing  $< 3$  m/e Ca. per 100 g. soil.

3. The formation of calcium carbonate in the calciferous glands of earthworms has led to the assumption that they need a great deal of calcium for metabolism. Since earthworms are scarce in very acid soils a calcium deficiency has been regarded as directly responsible. However the evidence to support either contention appears to be slender and it is suggested tentatively that soil acidity operates very indirectly on populations, primarily through the known limiting effect of shortage of exchangeable calcium on green plants and soil micro-organisms, which in turn determine the availability of food and ultimately the size of earthworm populations.

4. Populations are more uniform in replicate plots treated with specific fertilizers than in replicate untreated plots. An explanation in terms of soil exchangeable calcium is suggested.

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